PEAK - OFF PEAK REVENUE AND COST ALLOCATION MODEL

Herbert S. Levinson, Wilbur Smith and Associates

This paper develops an approach for allocating bus service operating costs and revenues between peak and off-peak periods. It shows how the economic performance (relative profitability) of peak-period bus service depends on three relative measures--relative peaking, load factors, and schedule efficiency - labor practices.

As an example, when the ratio of additional peak buses to base buses is 1.0 and the pay hours per bus hour for the additional buses are double those for the base buses, each bus in the peak would have to carry more than 1.5 times the base period ridership. When this ratio rises to 3, peak buses would have to carry double the passengers carried on each bus in the base period for the peaks to be as profitable.

The problem of peak-hour costs has been both persistent and pervasive in the transit industry. A 1916 study by the American Electric Railway Transportation and Traffic Association, set out to prove that: "it is the relation of income to expenditure between the hours of 9 A.M. and 4 P.M. that is the most favorable to the company"(1). Current operating experience suggests that high peak-to-base ratios of buses in service without a corresponding increase in load factors can produce a relatively poor cost-revenue picture for peak-hour service. For example, a 1974 analysis of costs and revenues for the Merseyside Transit System (England) found that revenue received from peak travelers did not cover costs of providing peak service, while off-peak revenue was more than covering costs (2).

The increased costs of additional peak services primarily reflects the extra driver costs resulting from increases in split-shifts and penalty payments. Another component relates to the increased costs associated with the extra peak-vehicles.

This paper outlines an approach to allocating costs and revenues between peak and off-peak riders. Its goal is to provide planning guidelines for estimating the economic performance of peak versus off-peak bus service. Accordingly, it develops a basis by which the relative profitability or loss of peak-period service can be estimated based on known operating parameters. It identifies the conditions under which peak-period service would be relatively more profitable than base service.

Relative profitability implies that the ratio of revenues to costs during peak periods is greater than that for off-peak periods. Actual profitability depends upon the relationships between fares, driver-wage rates, ridership, and amount of service provided.

The allocation of peak and off-peak costs are discussed first followed by revenue allocation. The final section develops a formula by which the relative profitability of peak-period bus service can be estimated, based on operating costs and revenues.

Bus Cost Allocation

The bus cost-allocation model context is shown in Figure 1, and the various parameters are further defined in Table 1.

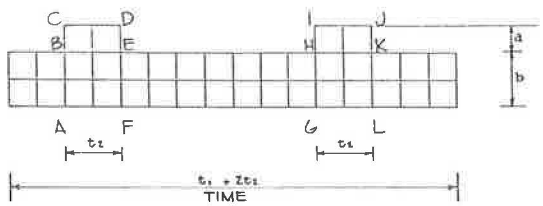
Figure 1 represents a simplified hourly variation pattern of the number of buses required throughout the day. It assumes that a uniform number of buses (b) would be required throughout the day for base service. An additional number of buses (a) would be needed during each peak period to provide the additional or excess peak service.

The costs of providing the additional (excess) peak-service (C_2) are associated with the two rectangles protruding as peaks (B C D E and H I J K). The costs of providing peak-hour service (C_p) represent these incremental costs, plus the pro-rated share of the base service costs (these costs relate to the rectangles A C D F and G I J L).

Bus operating costs typically relate to bus-miles, bus-hours and peak-buses operated. About 60 percent of the total operating cost relates to bus hours, 20 percent to bus miles, and 20 percent to peak-vehicles.

Bus-hours normally account for about 75 percent of the direct costs, and bus-miles 25 percent. Many properties further simplify cost analyses by relating direct operating costs to drivers' wages and bus-miles. For example, the Chicago Transit Authority estimates direct operating costs as 50 cents per bus-mile plus drivers' wages; labor costs account for about two-thirds of the total (3).

Figure 1. Bus Operating Cost Allocation Context.



Notes:

a = additional buses needed for peak.

b = base-period buses operated.

t_2= duration of each peak period.

COST OF ADDITIONAL PEAK PERIOD SERVICE - C_2, relates to rectangles B C D E and H I J K

OVERALL COSTS OF PEAK PERIOD SERVICE - Cp, relates to rectangles A C D F and G I J L

Table 1. Definition of Bus Operating Cost Parameters.

ITEM	(1) BASE SERVICE	(2) ADDITIONAL BUSES REQUIRED FOR PEAKS (△)
Time Period	$2t_2+t_1$	$2t_2$
Buses Required	b	a
Pay Hours/Bus Hour	P_1	P_2
Cost/Pay Hour	A	A
Miles Operated	M_1	M_2
Cost/Bus Mile	B	B

Ratio of △ peak to base Pay Hours/Bus Hour = P_2/P_1 = Y

Ratio of △ peak to base buses = a/b = X

Ratio of non-peak period to peak period $=\frac{t_1}{2t_2}=Z$

TOTAL BUSES OPERATED IN PEAK = a + b

The model uses these various parameters in a slightly modified form--it distinguishes between peak and off-peak pay hours per bus hour thereby taking into account the effects of labor agreements. Because drivers' wages represent the largest component of direct costs, and since the unit-maintenance-related costs associated with bus miles are essentially the same for peak and off-peak service, bus miles are subsequently eliminated to simplify the analysis.

The comparative operating costs for peak and base service can be derived as follows:

1. Costs of Base Service C_1

$$C_1=(2t_2+t_1)bP_1A+bM_1B \quad (1)$$

$$C \cong (2t_2+t_1)bP_1A \quad (2)$$

2. Costs of Additional (Excess) Peak Service C_2

$$C_2 \cong 2t_2aP_2A+aM_2B \quad (3)$$

$$C_2 \cong 2t_2aP_2A \quad (4)$$

3. Costs of Total Peak Service (Cp)

These costs equal the costs of the extra peak service plus the share of the base service, that should be pro-rated to the peak periods.

$$Cp \cong \frac{2t_2}{2t_2+t_1} C_1 + C_2 \quad (5)$$

4. Total Operating Costs (C_3)

Costs of base plus peak marginal costs

$$C_3 = C_1 + C_2 \quad (6)$$

5. The proportion of the total costs allocated to the peaks, S, is simply the ratio of (5) to (6).

$$S=\frac{\frac{2t_2}{2t_2+t_1} C_1 + C_2}{C_1 + C_2} \quad (7)$$

or, upon substitution of formulas 2 and 4.

$$S=\frac{2t_2\ (bP_1 + aP_2)}{(2t_2 + t_1)\ bP_1 + 2t_2aP_2} \quad (8)$$

Eliminating the component of costs associated with bus miles makes it possible to develop subsequent relationships based on relative values or ratios. Empirical analysis show that this simplified relationship tends to slightly increase the share of operating costs allocated to peak service, and in fact, represents an upper limit for the peak's share of total operating costs.

The preceding formula can be further simplified by substituting three ratios or indices, x, y, and z into the equation. This leads to the following expression for estimating the proportion of operating costs to be allocated to the peak periods (5).

$$S = \frac{1 + x\ y}{1 + x\ y + z} \quad (9)$$

Where:

x = ratio of additional peak to base buses

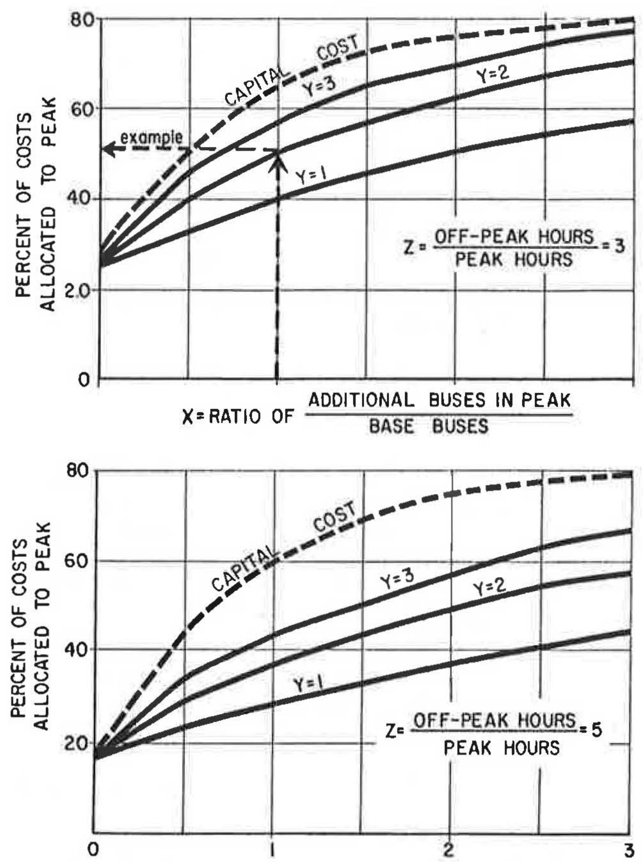
y = ratio of peak to base pay hours/bus hour

z = ratio of non-peak to peak period duration

s = share of daily operating cost allocable to peaks

Typical values of "S" are plotted in Figure 2 for the cases of $z = 3$ and 5. The curves show that the higher the peaking, the higher the share of costs attributable to peaks. Similarly, the higher the relative driver costs for peak-period service, the higher the share of costs attributable to peaks. When the peaks represent 25 percent of the daily time period (i.e., $z = 3$), they would account for about 50 to 70 percent of the total costs. When they represent 17 of the daily time period (i.e., $z = 5$), they would account for 35 to 55 percent of the total costs.

Figure 2. Typical Peak-Hour Bus Cost Allocations.



For example, when there is one additional peak bus, per base bus ($x = 1.0$) and the pay hours per bus hour for the additional buses are double those for the base buses ($y = 2.0$) approximately half of all bus costs are allocable to the peak periods for the case where $z = 3.0$.

The relative shares of capital (bus) costs attributed to the peak hours are also shown on Figure 2. They are based on the following formula:

$$S' = \frac{\frac{2t_2}{2t_2 + t_1} \quad b+a}{b + a} = \frac{\frac{1}{(1 + z)} + x}{1 + x} \qquad (10)$$

This formula shows that the peaks account for a consistently high proportion of total capital cost. For the case where $x = 1$ and $z = 3$, the peaks would account for about 63 percent of the capital costs. It should, however, be recognized that the capital costs associated with bus service are normally low relative to operating costs.

Revenue Allocation

The proportion of daily bus revenues which are allocable to the peak periods can be derived from a similar analysis. The basic parameters and ratios utilized are shown in Table 2.

Table 2. Definition of Bus Revenue Parameters.

ITEM	BASE PERIOD (Off-Peak)	PEAK PERIOD
Hours	t_1	$2t_2$
Trips/Hour	n_1	n_2
Passengers/Bus Trip	O_1	O_2
Fare/Passenger	D_1	D_2
Buses Involved	b	a + b
RATIOS		
Passengers/Bus Trip	$e = O_2/O_1$	
Trips/Hour	$f = n_2/n_1$	
Fare/Passenger	$g = D_2/D_1$	

Extra buses in peak/base service buses $Y = \frac{b}{a}$, as before

Off-peak hours/peak hours $\frac{t_1}{2t_2}$ as before

1. Peak Period Revenues (R_2)

$$R_2 = (a+b)\ n_2\ 2t_2\ O_2\ D_2 \qquad (11)$$

2. Off Peak Revenues (R_1)

$$R_1 = b\ N_1\ t_1\ O_1\ D_1 \qquad (12)$$

3. Total Revenue (R_3)

$$R_3 = R_1 + R_2 \qquad (13)$$

4. The share of revenue generated during the peak period, K,

$$K = \frac{R_2}{R_1+R_2} \qquad (14)$$

or upon substitution:

$$K = \frac{(a+b)\ n_2 2t_2 O_2 D_2}{(a+b)\ n_2 2t_2 O_2 D_2 + bn_1 t_1 O_1 D_1} \qquad (15)$$

Substituting the ratios e, f, g, as well as x and z into this formula produces the following result:

$$K = \frac{(1 + x)\ f\ e\ g}{(1 + x)\ f\ e\ g+z} \qquad (16)$$

For the case where the same fare per passenger is obtained (g = 1), and the same number of bus trips are operated per hour (f = 1), the formula becomes:

$$K = \frac{(1 + x)\ e}{(1 + x)\ e + z} \qquad (17)$$

Comparing Costs with Revenues

The question "are the peaks more or less (relatively) profitable?" can be answered by comparing their relative shares of revenues generated and costs incurred. For peak-period bus service to be more relatively profitable than the base-period service, the proportion of revenues generated, K, (Formula 16 or 17) should be greater than the proportion of costs incurred. (Formula 9.)

That is, $K > S$ (18)

Upon substitution, this inequality becomes

$$\frac{(1+x)\ e}{(1+x)\ e + z} > \frac{1+xy}{1+xy+z} \qquad (19)$$

Algebraic simplification leads to the following approximate relationship which defines the conditions when peak period service is more profitable in relative terms.

$$e > \frac{1 + z\ y}{1 + x} \qquad (20)$$

Where:

e = ratio of peak to base passengers per bus

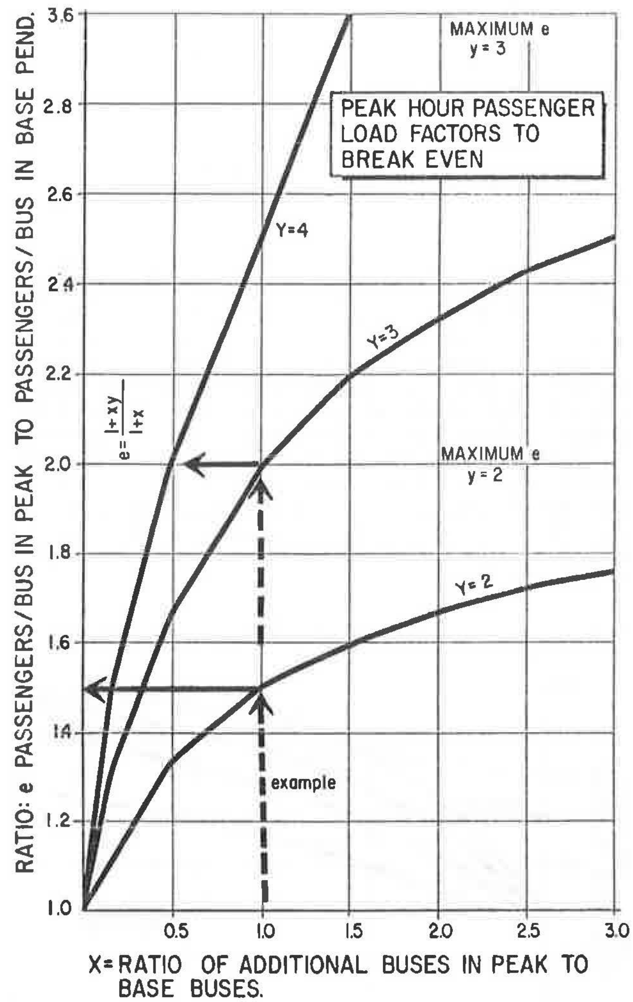
x = ratio of additional buses to base buses

y = ratio of pay hours/bus hour additional peak buses to base buses

This function is plotted in Figure 3 for the cases where y equals 2, 3, and 4. The term y is significant since the extent that it deviates from unity is a function of labor contracts and scheduling inefficiency.

(a) If the base ratio of pay hours per bus hour could be realized by peak period tripper services, then the peaks would be equally as profitable (or unprofitable) as the base, when equal load factors are attained.

Figure 3. Peak Hour Passenger Load Factors to Break Even.



(b) In contrast as the ratio, y, increases, there is a rapid rise in the relative peak-hour loads required for buses.

(c) Typical values, based on experiences of a range of cities are as follows:

x - ratio of additional buses to base buses, 1.00 to 2.00 (corresponds to peak-to-base ratios of 2.00 to 3.00)

y - ratio of peak to base pay hours per bus hour, 1.30 to 2.00

As an example, when the ratio of additional peak to base buses (x) is 1.0, and the pay hours per bus hour for the additional buses are double those for the base buses (y = 2) each bus in the peak periods would have to carry more than 1.5 times the base period ridership. When the ratio y rises to 3, peak buses must carry more than double the passengers carried in the base buses for the peaks to be as profitable. The corresponding value for y = 4.0 would be 2.5.

Summary and Significance

The analysis has shown how the relative profitability of peak-hour bus services can be approximated from three basic ratios. These are:

- the ratio of additional buses required for peak service as compared with those required for base service (x). This is, in essence, a peaking factor.
- The ratio of pay hours per bus operated for the additional peak buses required as compared with that for the base buses (y). This reflects schedule efficiency and work rules regarding split shifts and overtime.
- The ratio of peak-hour passengers per bus to off-peak passengers (z). This reflects peak and off-peak load factors.

It is clear that peak-hour service can be relatively profitable where peaking is limited, high levels of bus schedule efficiency can be attained, and peak-loads per bus are substantially higher than those during base service. However, in many communities, the peaks will be relatively unprofitable--a condition that could be alleviated by charging higher fares during the peak hours.

The analyses involve simplifying assumptions with regard to certain cost components. However, such simplifications do not appear to substantially change the relationships. Moreover, excluding bus-mile related costs partially counterbalance excluding capital cost elements. There are also some varitions resulting from the simplifying assumptions regarding the demand curve (i.e., omission of owl service).

The target cost-revenue ratios can serve as a management tool, and provide a point of departure. It is realized that many other factors must also be considered--and may take precedence, where service is to be reduced or eliminated.

In application, analysis should be done on a line-by-line basis and then aggregated for the total system. Interpretation and refinement of results should take into account base-period policy headways and service operated because drivers are available. Further adjustments for these practices would provide a clearer picture of the true economic performance of peak-period urban bus services.

References

1. "Report of Committee on Cost of Rush-Hour Service, 1916 Convention of American Electric Railway and Traffic Association" reported in Henry W. Blake and Walter Jackson Electric Railway Transportation, New York City, 1924.
2. Arthur Anderson & Co., Bus Route Costing for Planning Purposes - Volume 1 - Report for the Transport and Road Research Laboratory, London, 1974.
3. Chicago Transit Authority - Operating Costs Per Vehicle Mile-Period, 1-6, 1975 - Op.-x-75161.